# Selected Enhanced Fidelity AIM Methods


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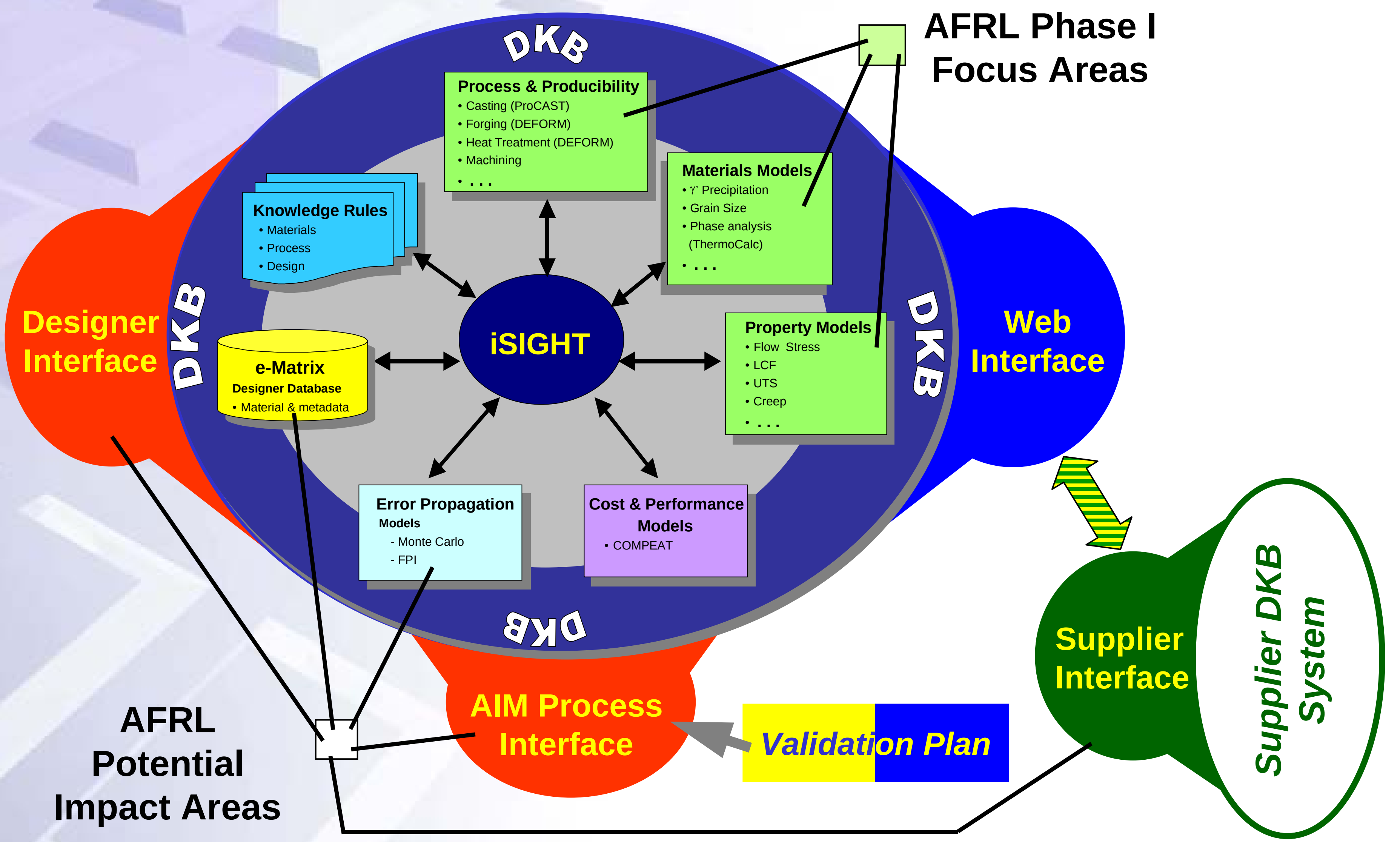
# AIM System Architecture




***Requirements flow from AIM architecture***

# What About Phase II & Beyond?

In general, demand is for methods to treat unknown (without database)

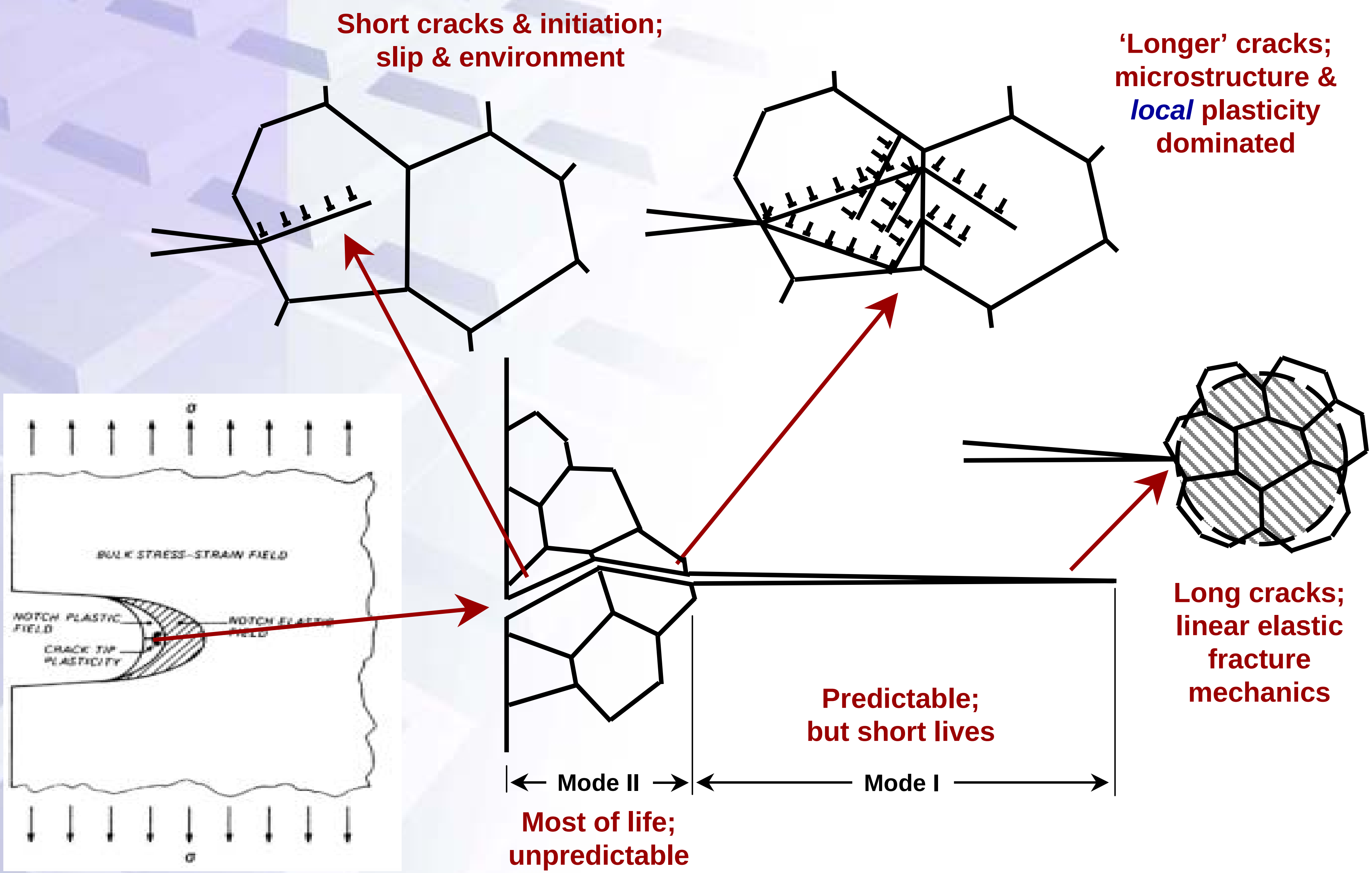
Numerical descriptions needed for scope & fidelity in performance prediction (property minima & fracture are locally dominated)

These require development and adaptation to system architecture

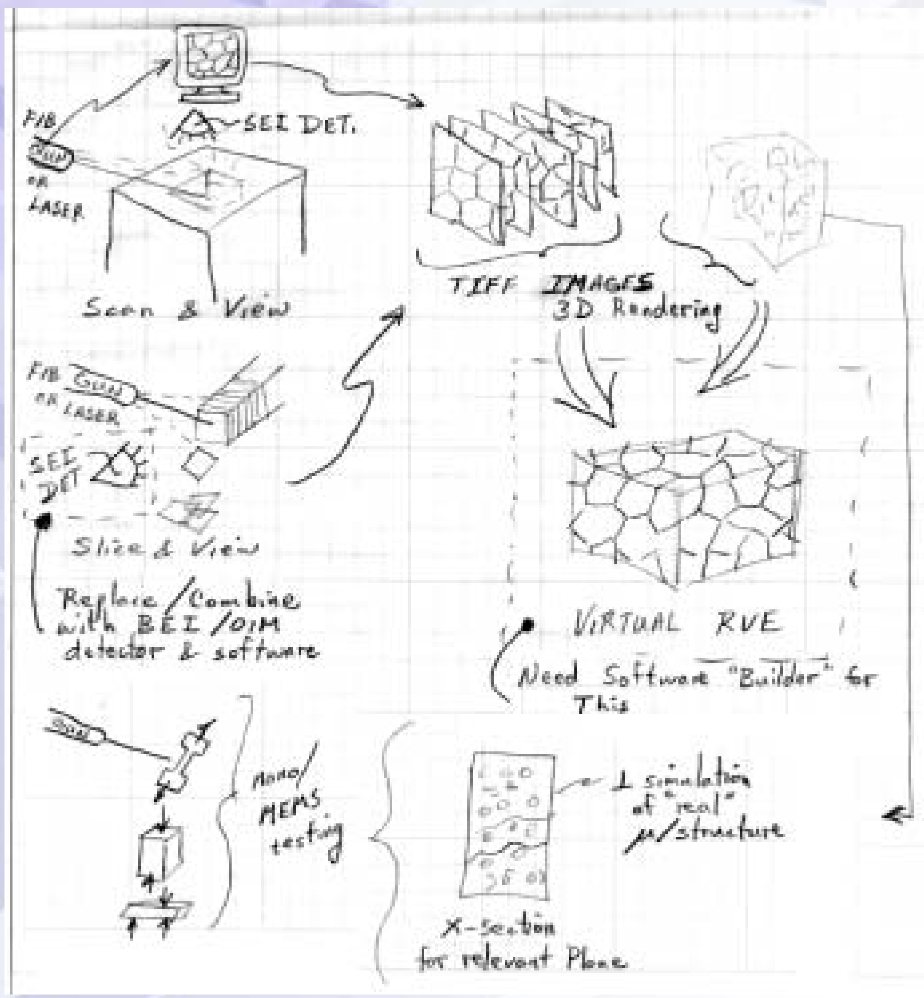
Thus AFRL Focus:

- Prediction, quantification & representations of structure evolution & kinetics
- Structure-sensitive numeric descriptions of properties
- Overlay of ‘homogenized’ or ‘fast-acting’ models, validation/tuning procedures, & interlace with design/architecture

# Need for Microstructure-Based Plasticity



# From Concepts to Realities




*Last year's 'sketchy' concept*

## *Briefings on Today's Progress*

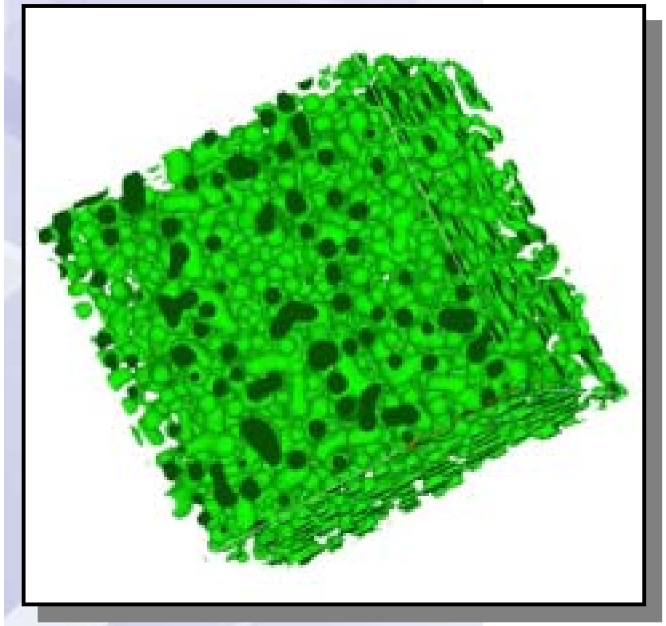
**Phase Field (Simmons, 20min)**

**Plasticity Modeling (Parthasarathy, 20min)**

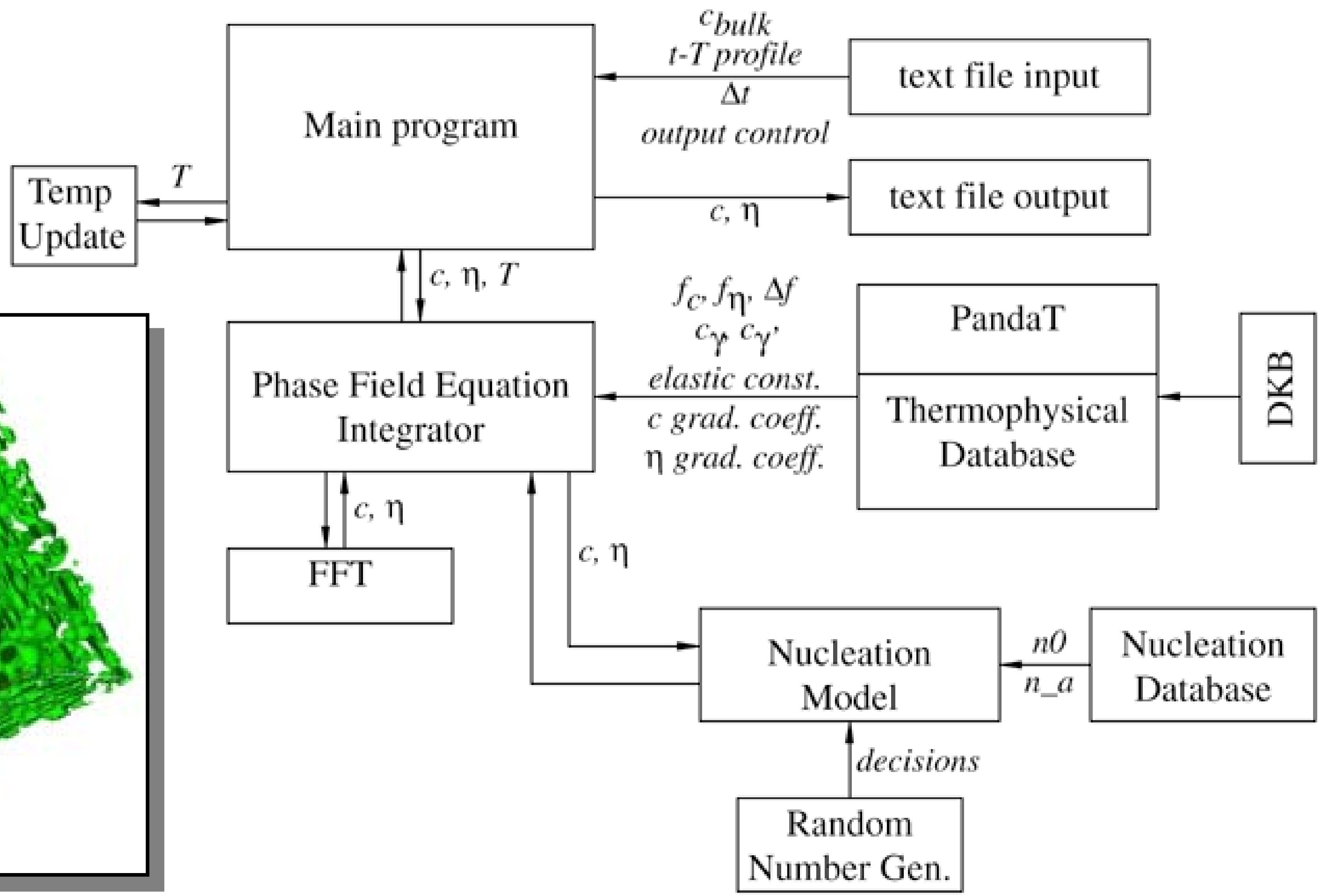
**Advanced Experimental Methods**
- **3D Quantification (Uchic, 10min)**
- **Representation (Simmons, 15min)**
- **Micro- & Nano-scale Tests (Uchic, 15min)**

**Broader View & Discussion (Dimiduk, All)**

# *Architecture & Implementation of Phase Field Software*



3D, Isothermal γ-γ' Coarsening



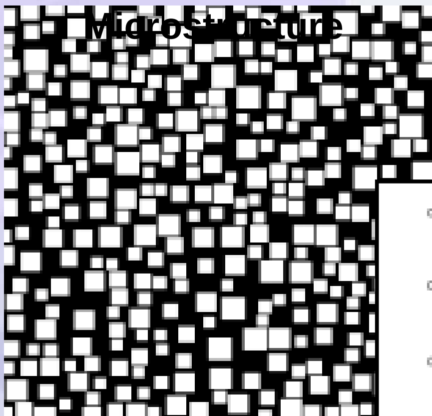

**Clear framework identified…real dimensionality, thermodynamics evolving!**

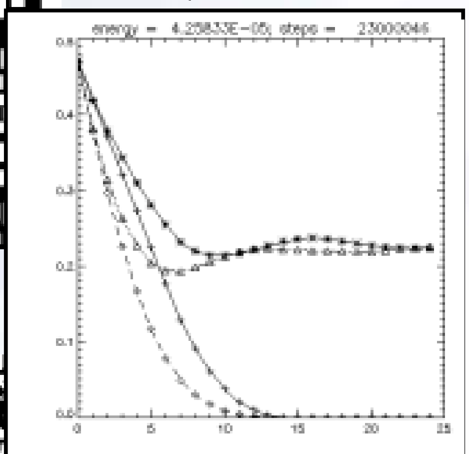
Simmons, Woodward, Wen, Menon, Shen & Wang, 2002

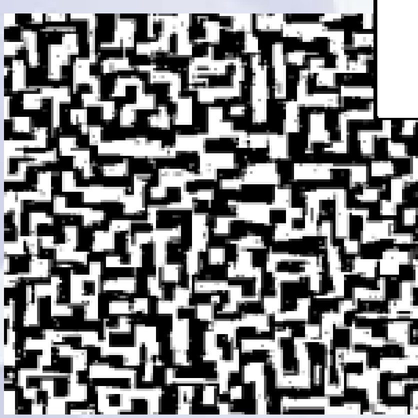
# Microstructure Representations

## 2-Point & Lineal Path Functions

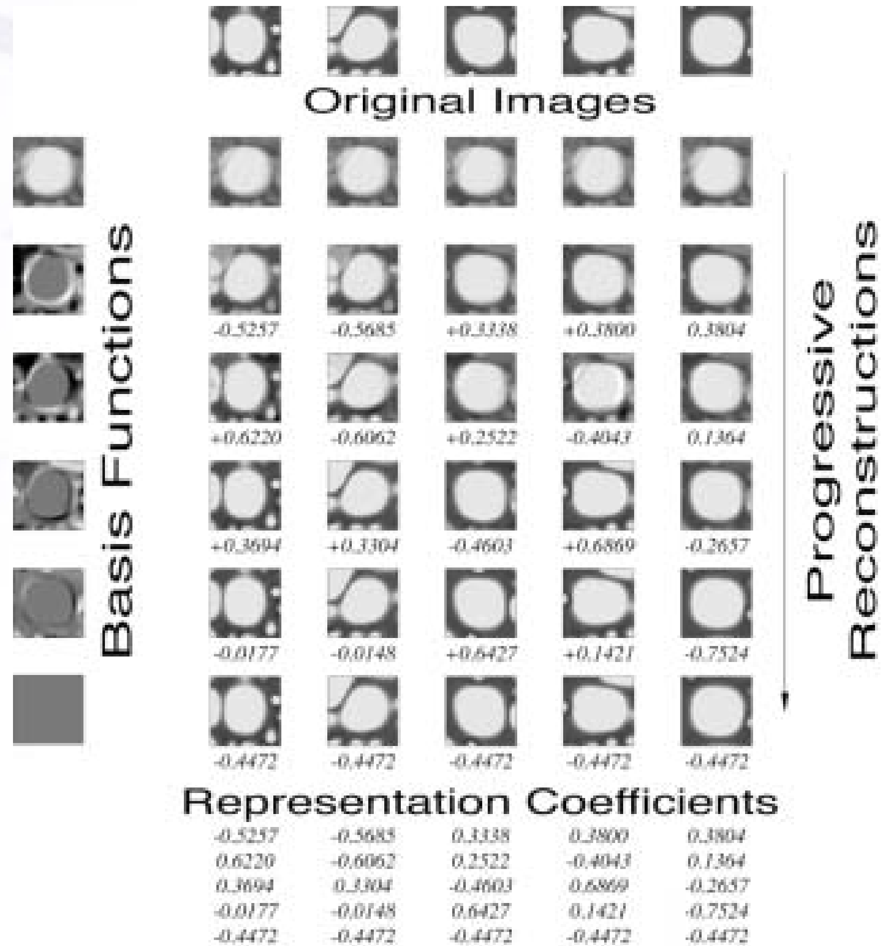
**Idealized Microstructure**





**Monte Carlo Reconstructed Representative Microstructure**




## *Principal Component Analysis (KLT)*

**Revolutionary longer-term approach to capture all information contained in microstructure**

# Beyond Analytical Strength Models

**Needs Development Within Atomistics**

$$\sigma_y\left(C_i, T, \varepsilon, \dot{\varepsilon}, \ldots\right) = f_\gamma\left(\frac{T_o}{T}\right)\left(\sum_i \frac{dc}{\sqrt{dC_i}}\sqrt{C_i}\right) + Mf_t\left(\frac{\Gamma_{APB}}{b}\right)$$

**Obtain by Dislocation Kinetics Simulation**

$$+ \; M\frac{4}{\pi^{1.5}} \cdot \frac{T_L}{bd_s}\sqrt{f\left(1-f_p\right)}\sqrt{\left(\frac{\pi d_s \Gamma_{APB}}{2T_L}-1\right)}$$

**strong coupling**

$$+ \; M\left[\left(\frac{\Gamma_{APB}}{2b}\right)^{1.5}\sqrt{\frac{2bd_s f\left(1-f_p\right)}{T_L}} \cdot \frac{4}{\pi^{1.5}} - \frac{\Gamma_{APB} f\left(1-f_p\right)}{2b}\right]$$

**weak coupling**

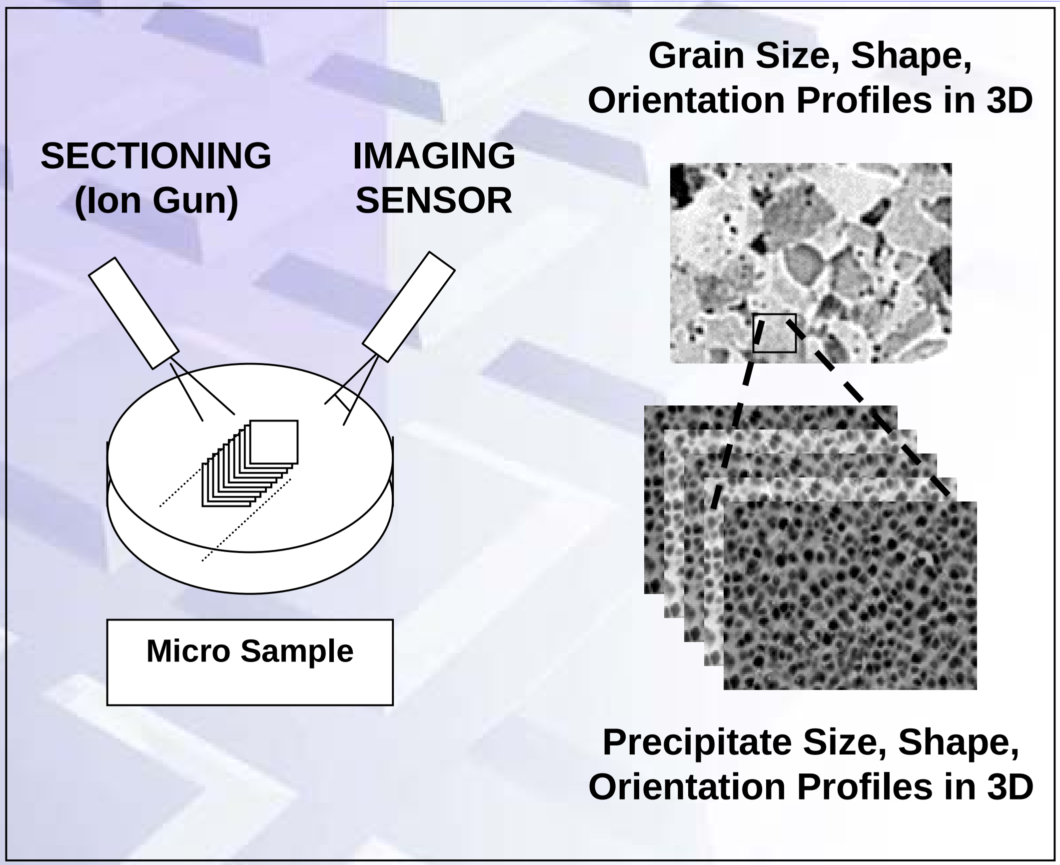
see Reppich

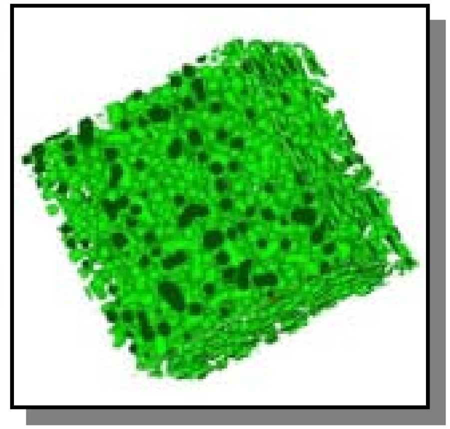
**Obtain by FEM Simulation of Grain Distribution Effects**

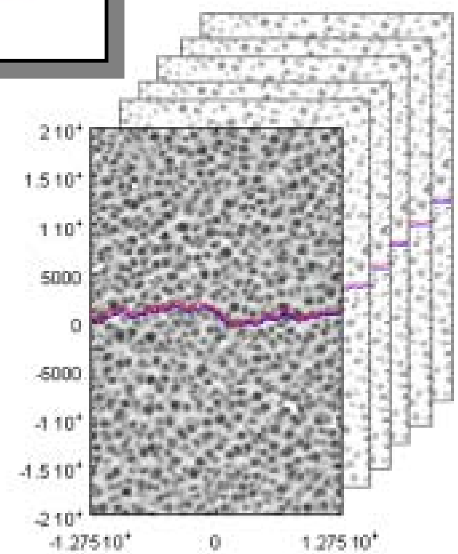
$$+ \; f_p\left[\sigma(T)_{Ni_3Al} + \sum_i\left(\frac{dc}{dC_i}C_i\right)\right] + f_p k_y^{\gamma'}\frac{1}{\sqrt{d_{\gamma'}}} + \left(1-f_p\right)k_y^{\gamma}\frac{1}{\sqrt{d_\gamma}}$$

**Numeric methods need and interface to AIM system**

# Unknown New Materials





**3D sectioning experiments** ➡ **3D virtual structure representations**

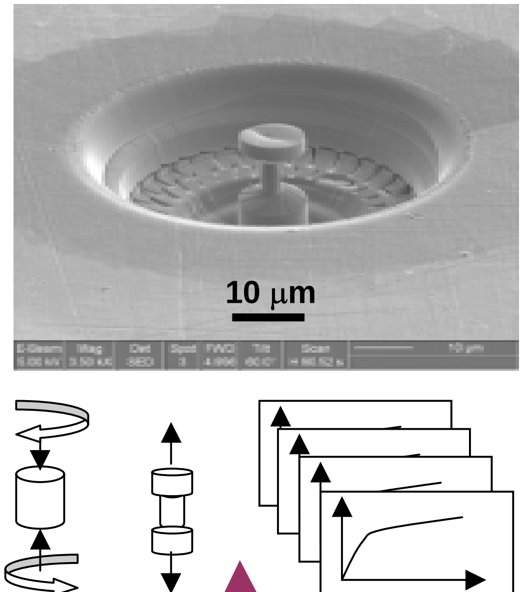
**Advanced simulation & experiments** ➡ **intrinsic grain-level properties**

**Small-scale property measurements** ➡ **model parameterization**

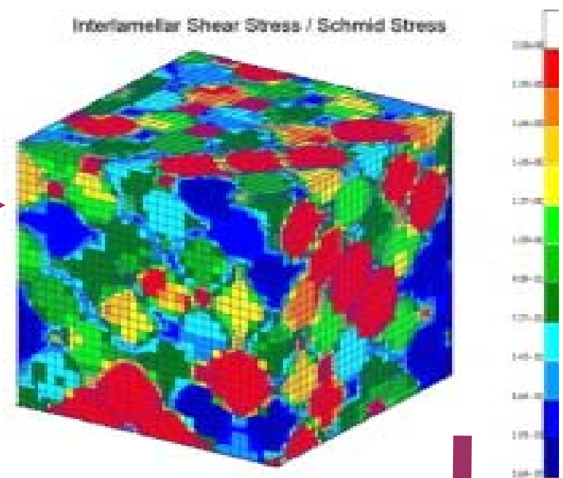
Dimiduk, Parthasarathy, Uchic, and Rao, 2002

AIM Accelerated Insertion of Materials

# Treating Unknown New Materials



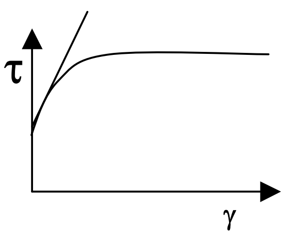

**Multiaxial FEM Analysis Of Polycrystalline, Polyconstituent Material**




**Plastic Heterogeneity & Strain Localization**

**Properties of Representative Volume Element (RVE) From Mesoscale and Analytical Tools**

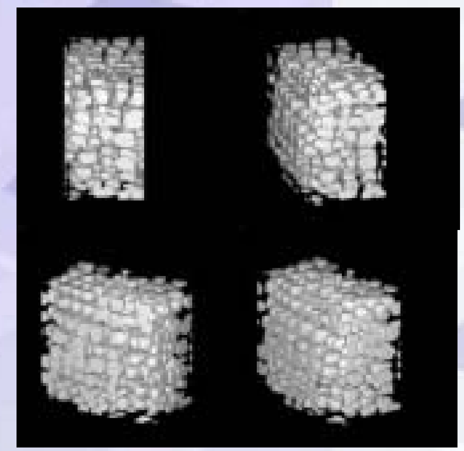
$$\dot{\tau} = \left\{h - \left(\frac{\tau - \tau_o}{\tau_s - \tau_o}\right)h\right\}\left(\dot{\gamma}/\dot{\gamma}_o\right)^m$$

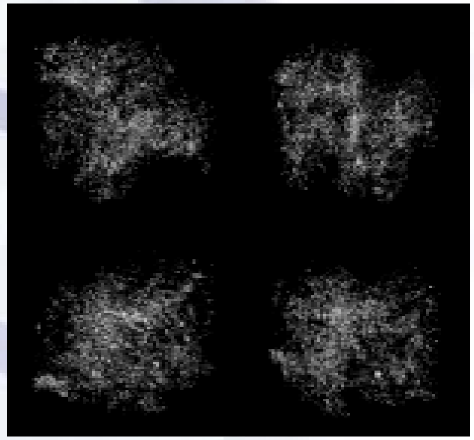



**Microstructure-Sensitive Representations (UMATs for 'intrinsic material' RVEs; results used in Ramberg-Osgood or Walker-like forms, or "Curve Generator," etc)**

Dimiduk, Parthasarathy, Uchic, and Rao, 2002

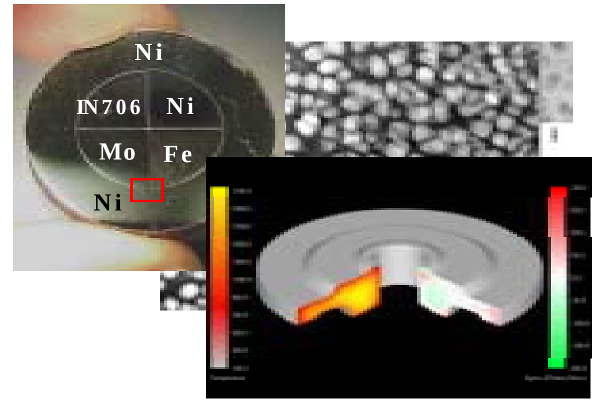
# Efficient Experiments for New Materials



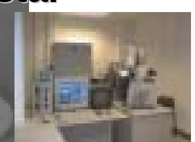


3-Dimensional Characterization of $\gamma$' and Carbides

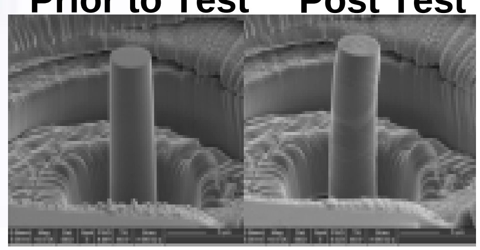
Rapid Experiments, Modeling, & Characterization

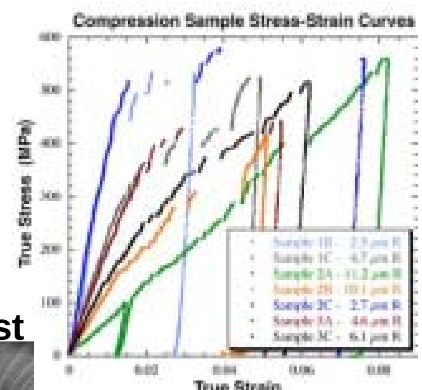







Prior to Test Post Test

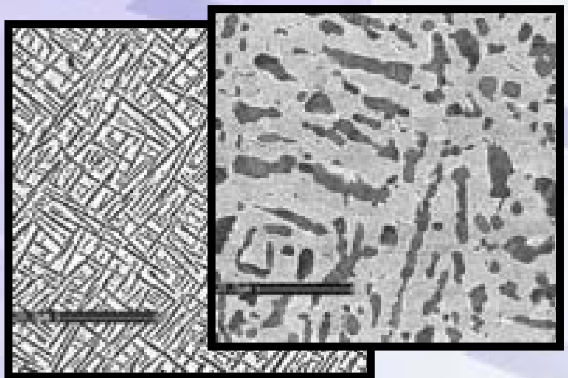
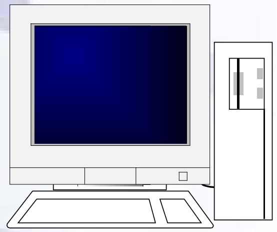
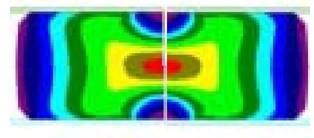




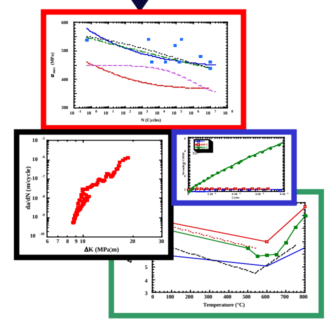

Micro- & Nano-Scale Property Measurement

**Unprecedented Novel & Efficient Experiments Emerging!**

# Payoff: Materials & System Prognostics


Materials Mathematics Experiment Experience



**Property Database**

Mathematics

State Awareness

Failure Physics

Data Fusion

Reasoning System

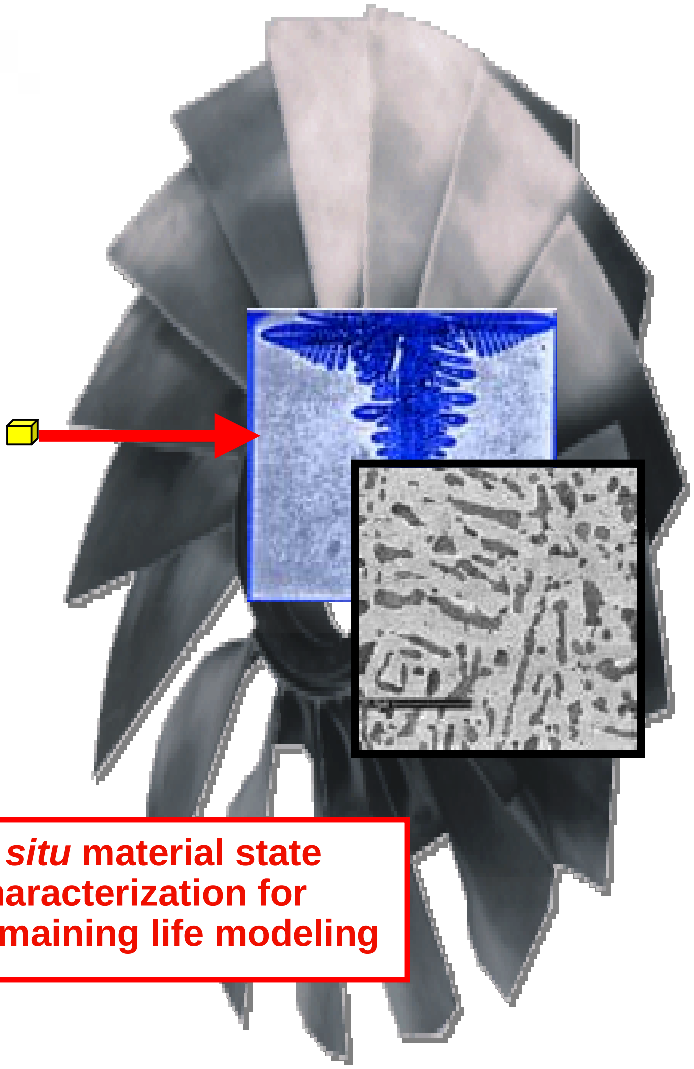
***Prognostics***




**Combat System Readiness**

# Material State Definition

- Characterize each disk's microstructure and damage state at the mesoscale
- Utilize DARPA/AF AIM technology – stochastic life prediction
- Material state sensing
  - Electron backscatter diffraction (EBSD)
  - Acoustic attenuation
  - Others…
- Define the probability of cracking for each disk



***In situ* material state characterization for remaining life modeling**

# MS & E Paradigm